



Hardware Demonstration of the Feasibility and Value of Distributed Resources as a Solution to the Sensitive Load Problem

Chris Houle (M.S. student)

Mahesh Illindala (Ph.D. student)

Robert Lasseter

Giri Venkataramanan

Electrical and Computer Engineering

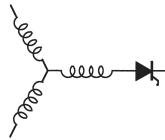
University of Wisconsin-Madison

Holly Thomas

NREL, Technical Monitor

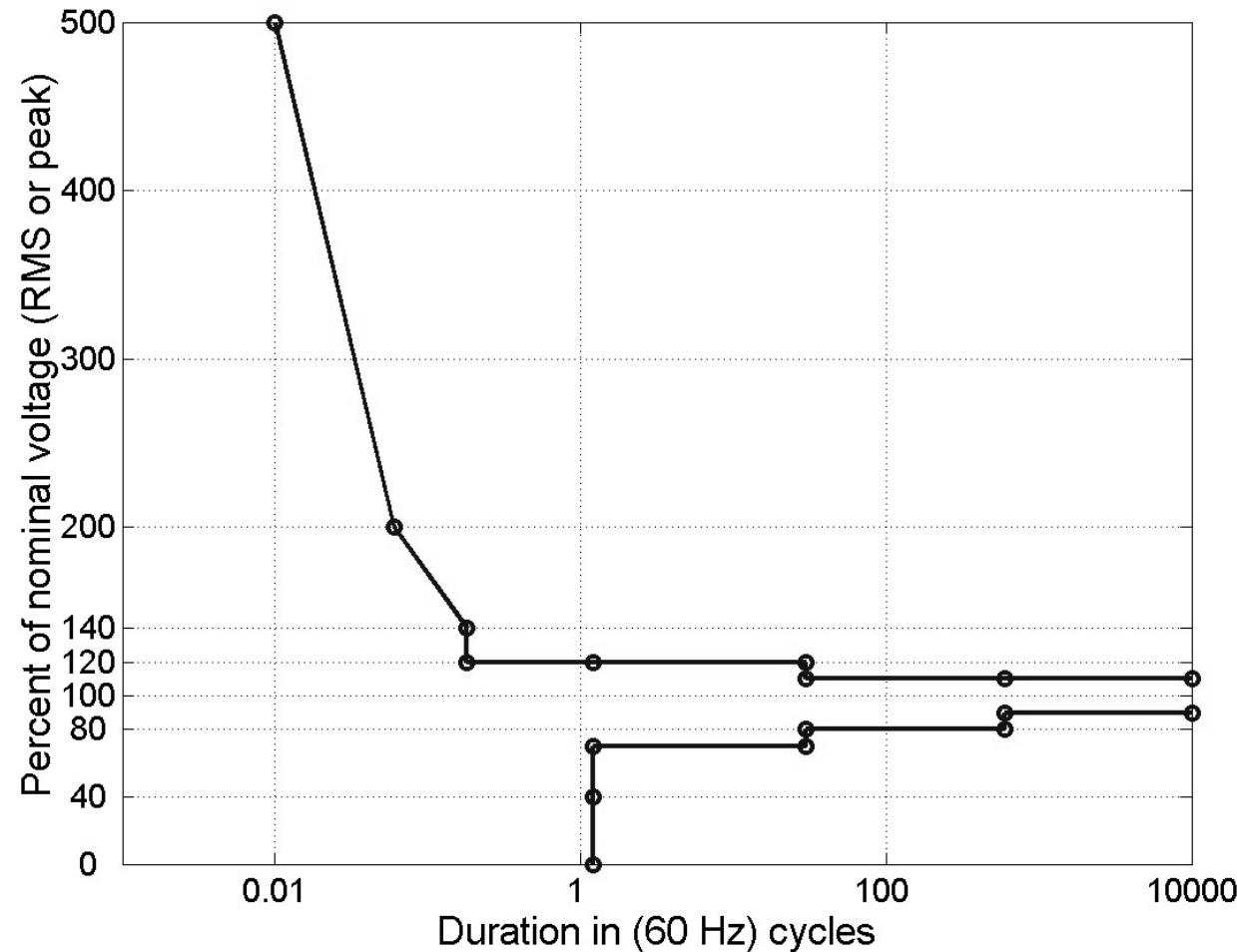
Project Objective

- Enable inverter based DR sources to meet demands of sensitive loads
- Enable parallel clusters of DR sources to operate in a stable manner without communication



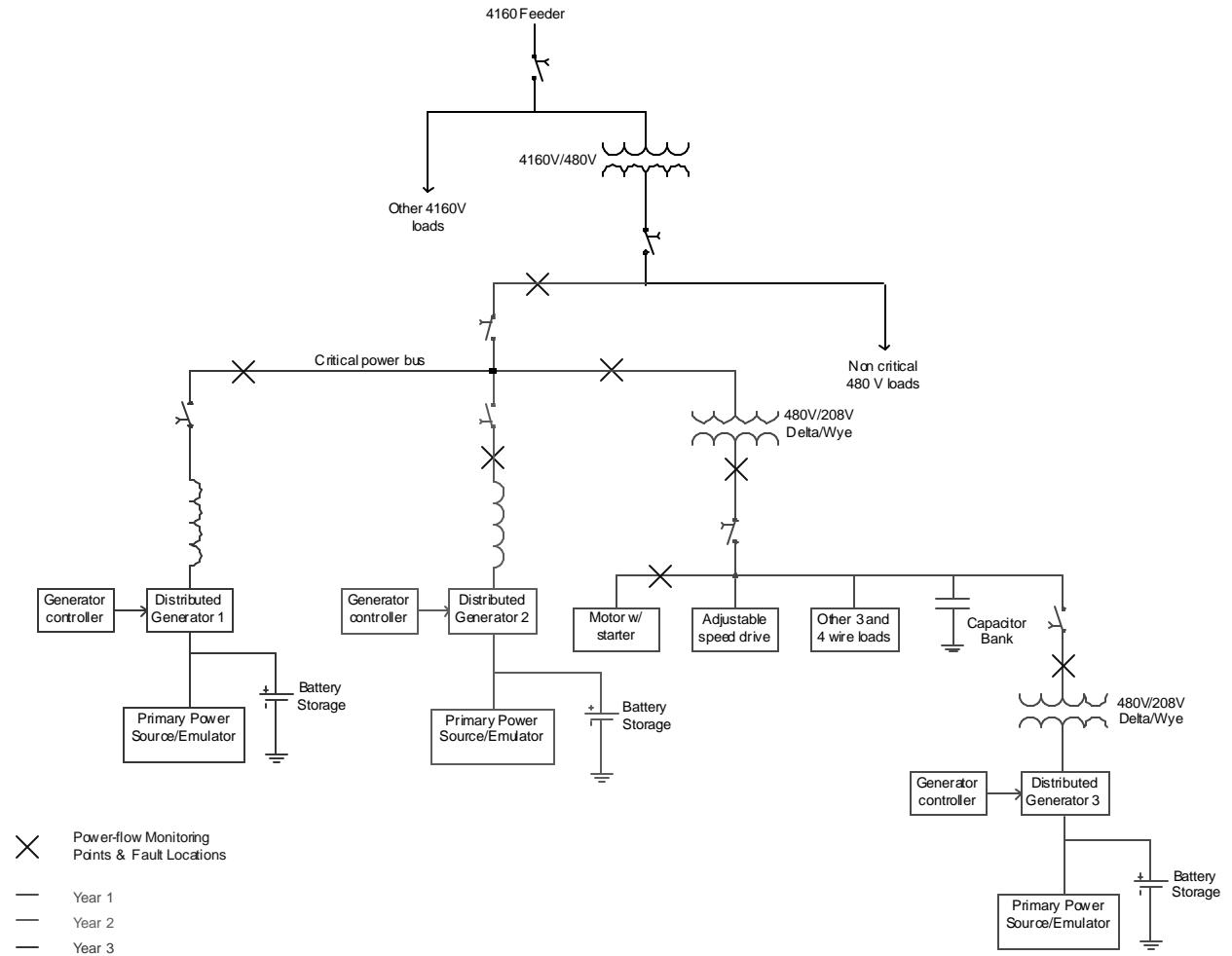
WEMPEC

Typical susceptibility limits



Proposed Hardware Platform

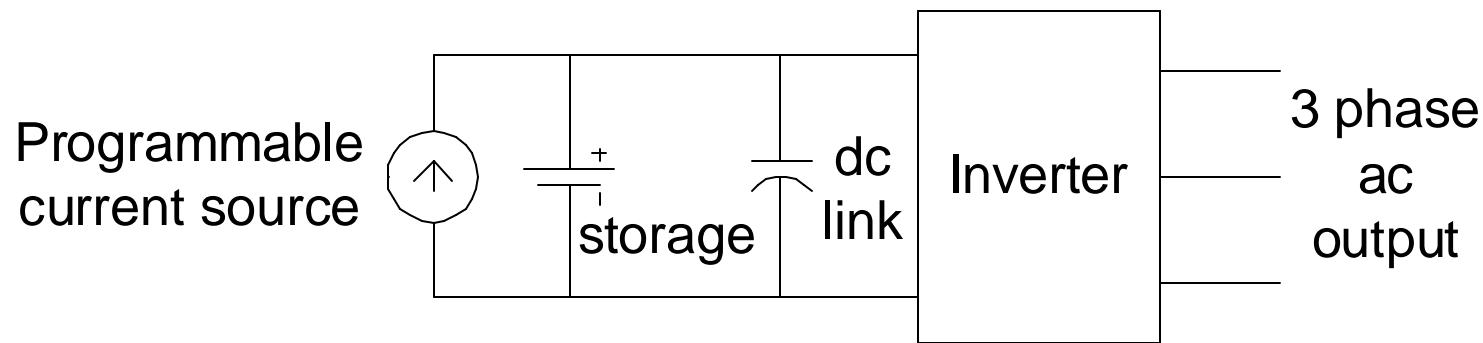
- Three inverters
- 3 wire and 4 wire
- Islanding and reconnection
- Direct & transformer coupling
- Complex loads
- Power source emulation
- Energy storage emulation
- Decentralized control



Control Objectives

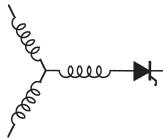
1. Real Power-Frequency Droop Characteristics
2. Reactive Power-Voltage Droop Characteristics
3. Address short term power quality issues
4. Ride through nominal amount of voltage sags and frequency deviations in a benign manner
5. Island and feed local critical loads upon large deviation
6. Reconnect upon system recovery seamlessly

Hardware Approach

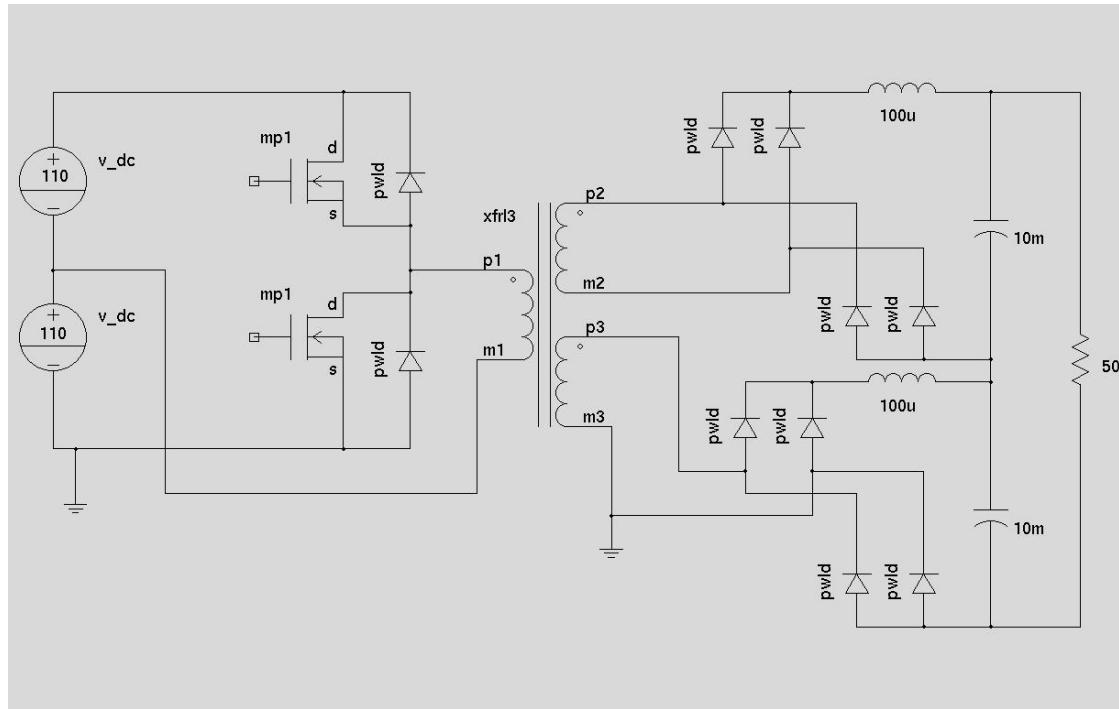


Year 1 Tasks

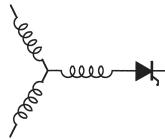
1. Development of Power Source Emulator (PSE)
2. Study of Energy Storage Requirements (ESR)
3. Demonstration of Operation of Single Inverter (DSI)
4. Development of Inverter with Distributed Generation Control Interface (DGC)
5. Computer Simulation Support (CSS)



1. PSE

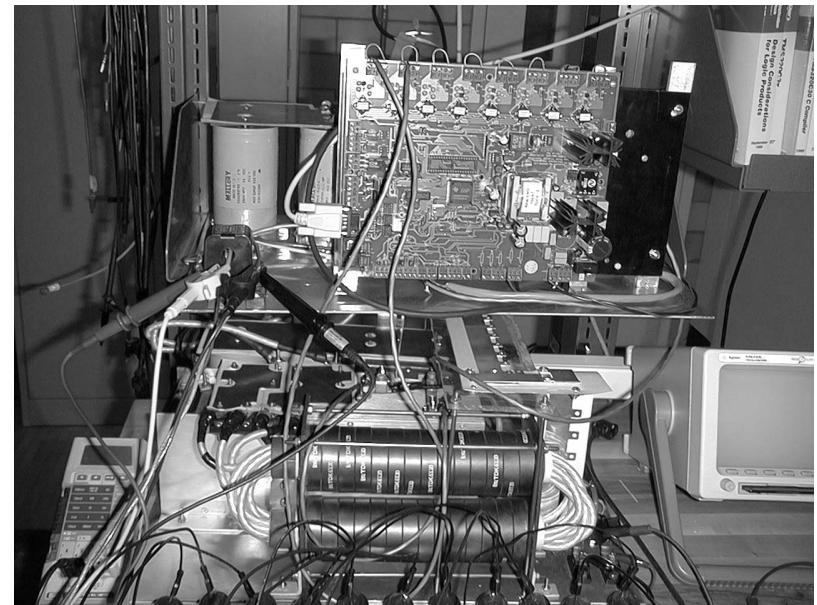
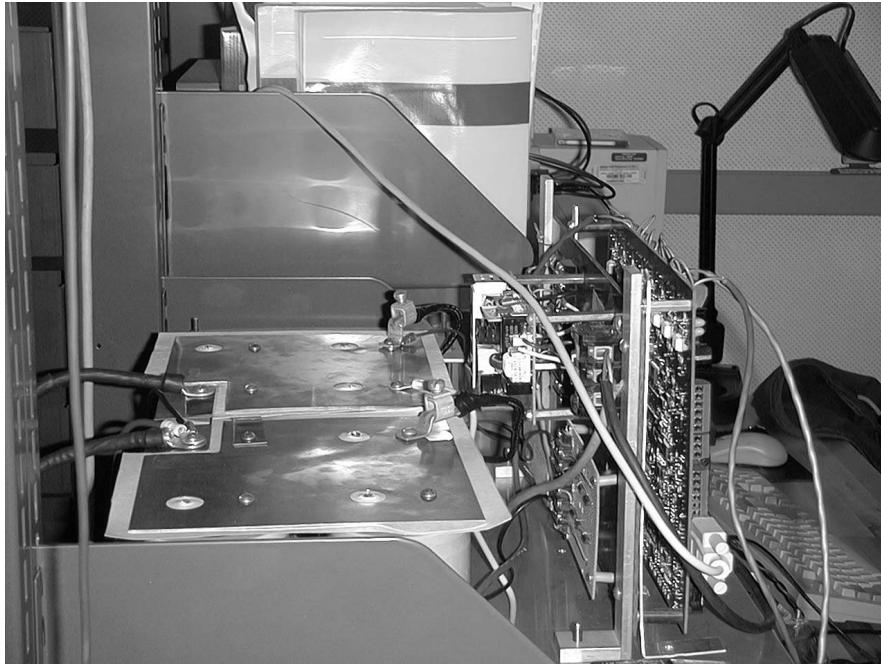


- Programmable voltage and current capability
- Allow source and battery modeling
- Incorporate effects of battery management functions
- Plan B – commercial converter



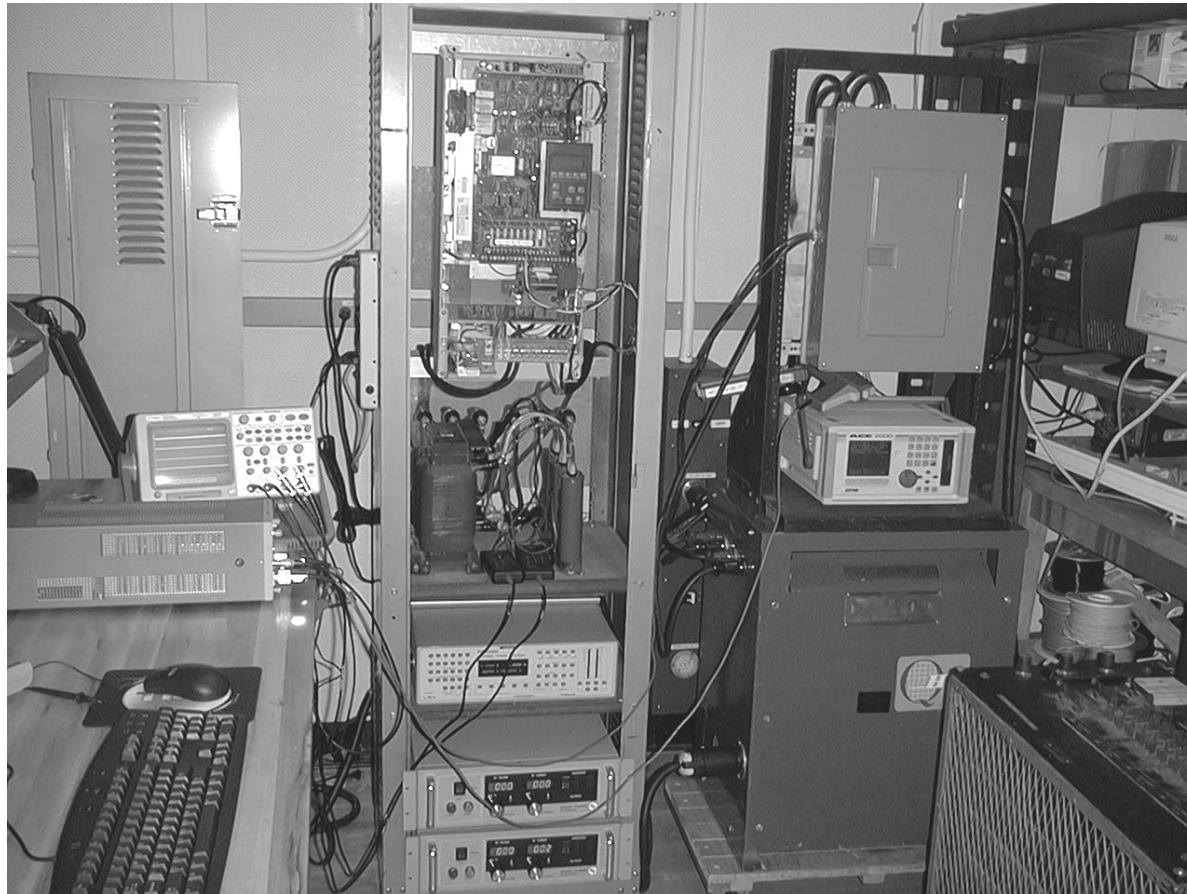
WEMPEC

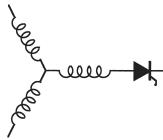
1. PSE





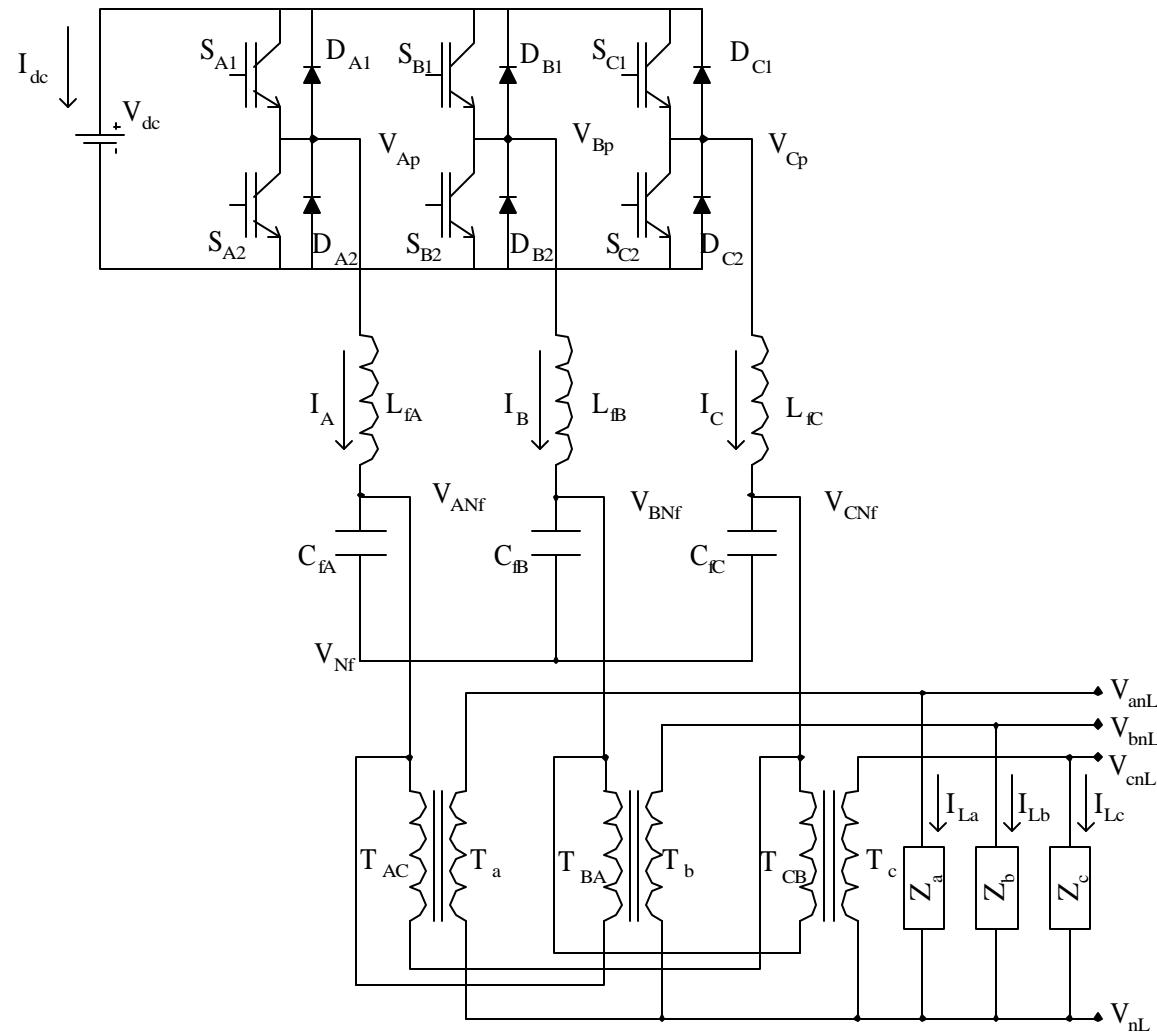
3. DSI

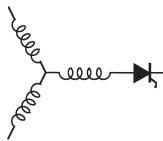




WEMPEC

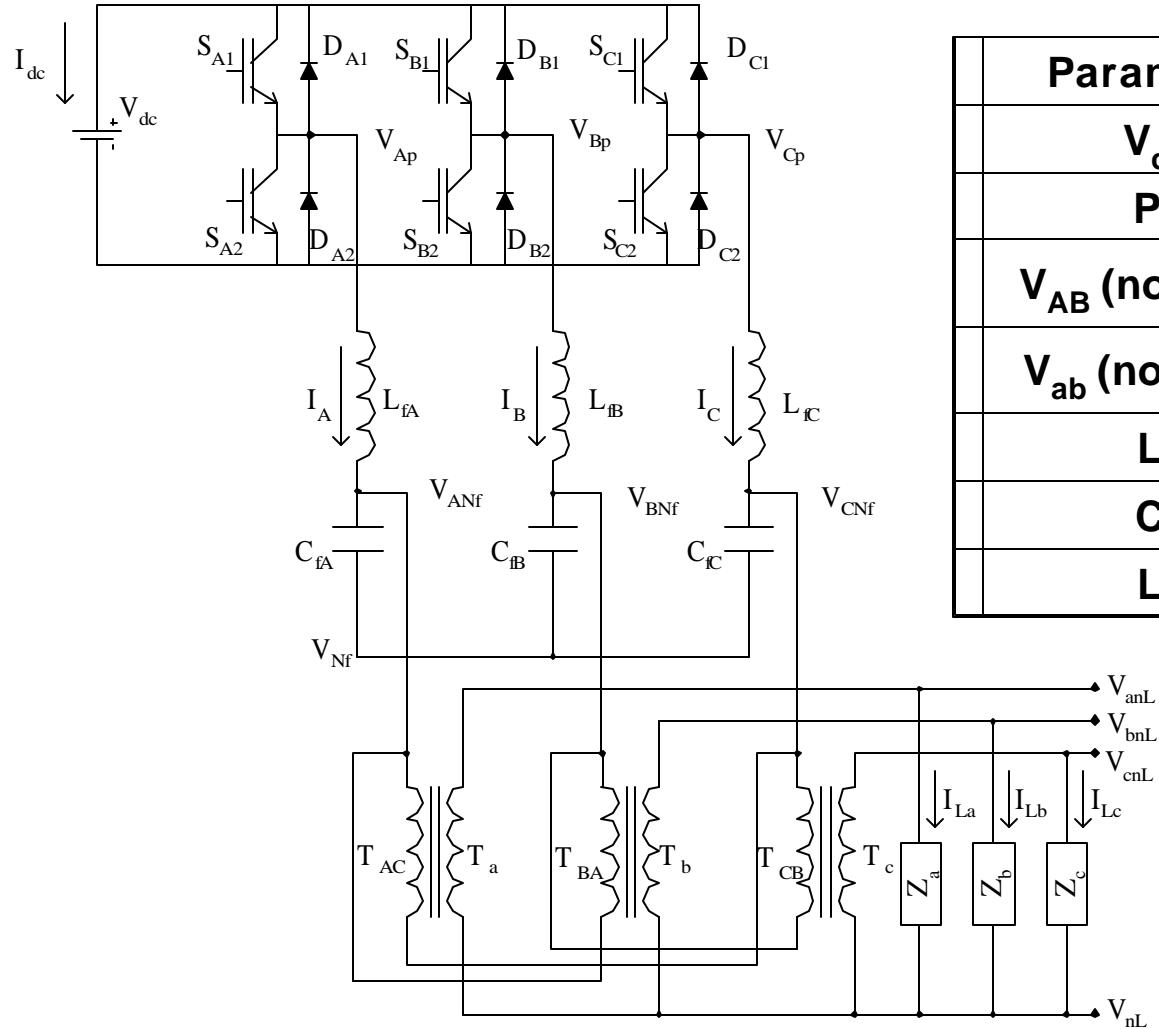
3. DSI



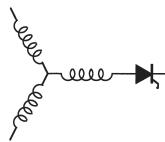


WEMPEC

3. DSI



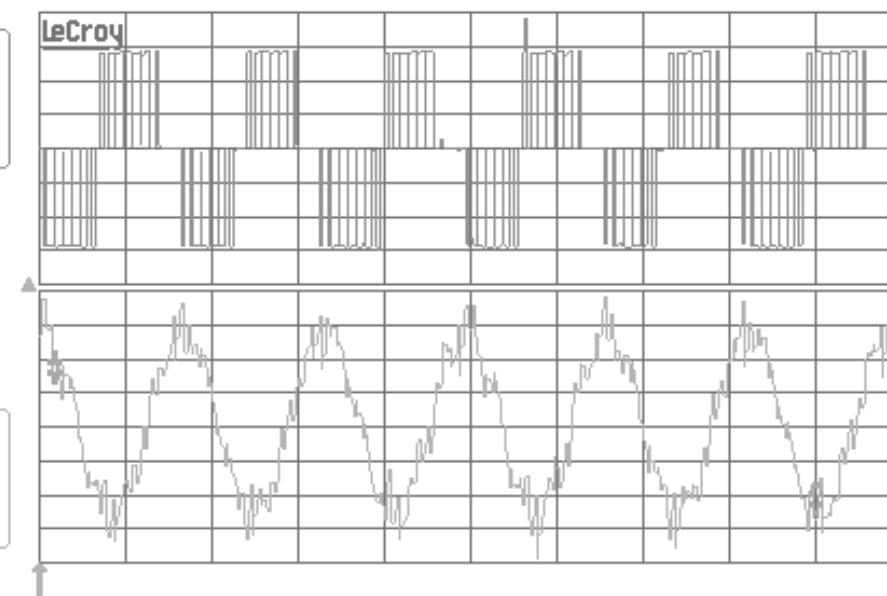
Parameter	Value
V_{dc}	750 V
P_o	15 kW
V_{AB} (nominal)	480 V
V_{ab} (nominal)	208 V
L_f	0.97 mH
C_f	180 μ F
L_t	2.1 mH



3. DSI

20-Jun-01
17:09:38

Reading Floppy Disk Drive

3
10 ms
250 V4
10 ms
10.0 A

CHANNEL 3

Trace
OFF On

Coupling

ZOOM

FIND

Gain
Fixed variableOffsets in
Volts
 DivisionsGrids
Single Dual
Quad Octal

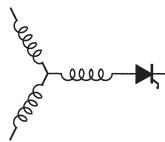
11 sweeps: average low high sigma

pkpk(4)	7.6 A	0.6	76.9	23.0
mean(4)	-0.23 A	-0.64	-0.18	0.14
sdev(4)	1.90 A	0.16	19.29	5.77
rms(4)	1.98 A	0.25	19.28	5.74
10 ms BWL ampl(4)	4.2 A	0.6	38.8	11.5

1 .1 V DC 5002 10 mV 50Ω 5003 .5 V DC 5004 .5 V AC 20

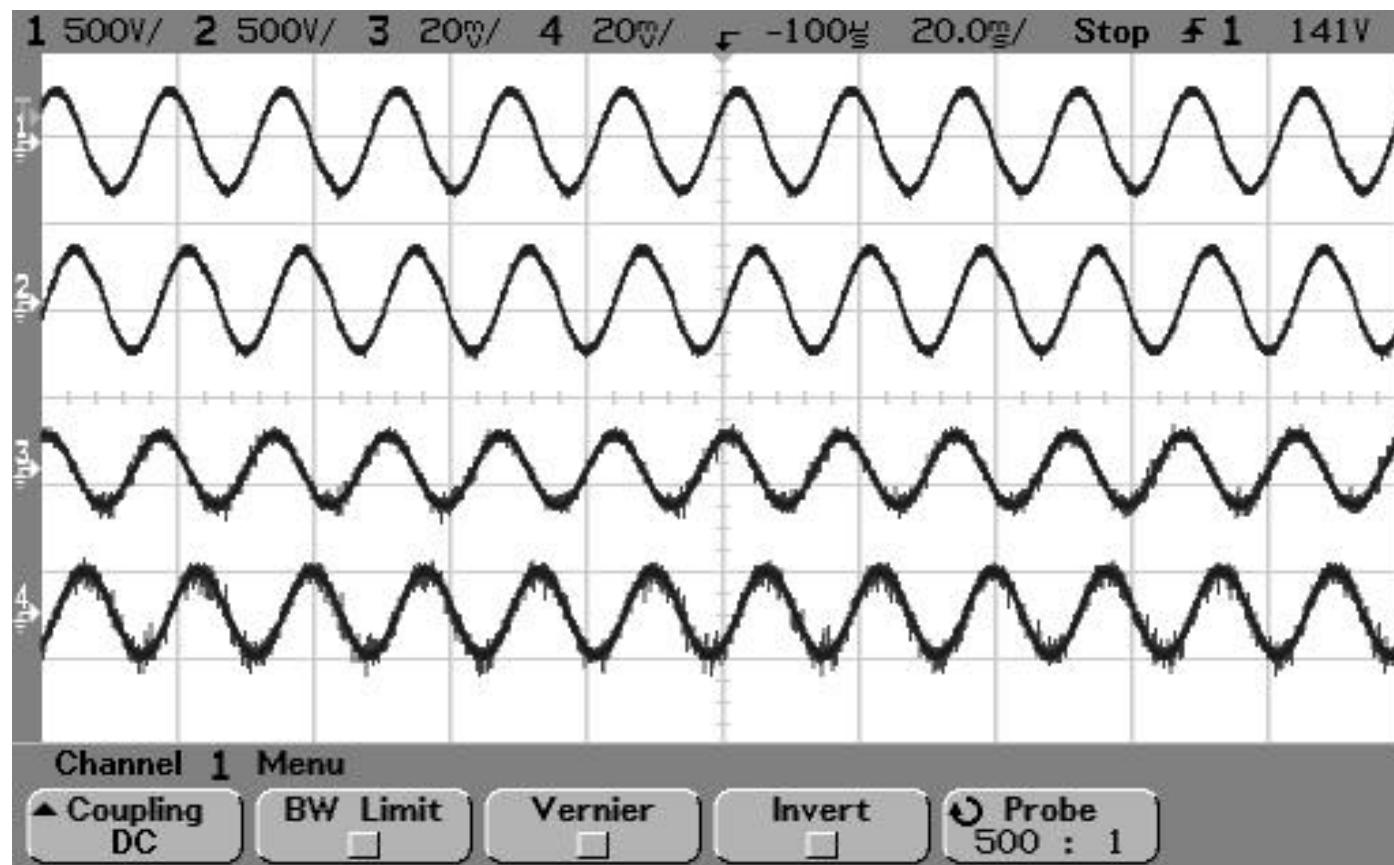
5 kS/s

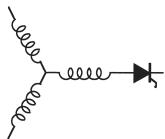
 STOPPED



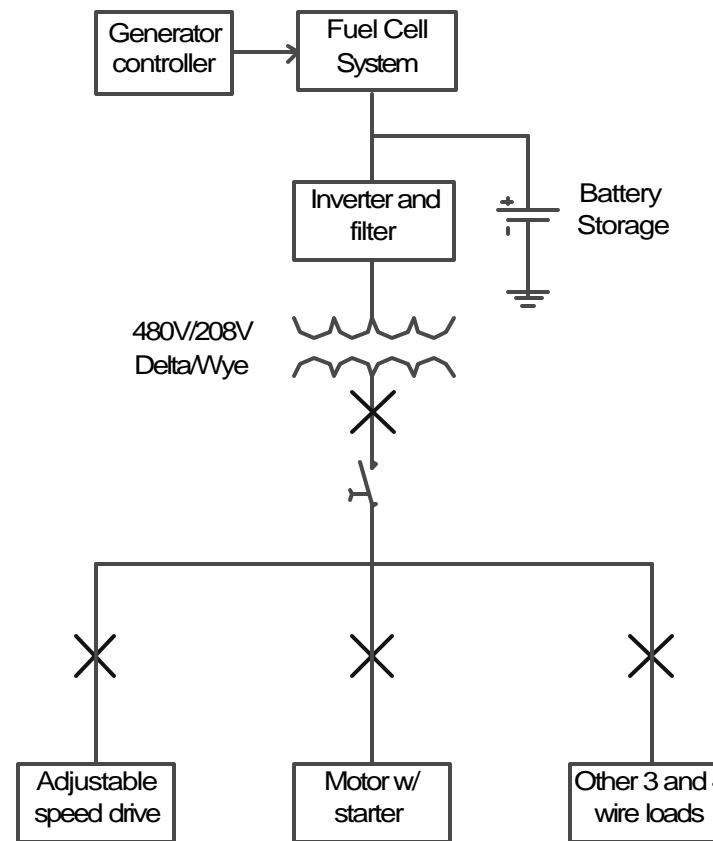
WEMPEC

3. DSI





3. DSI



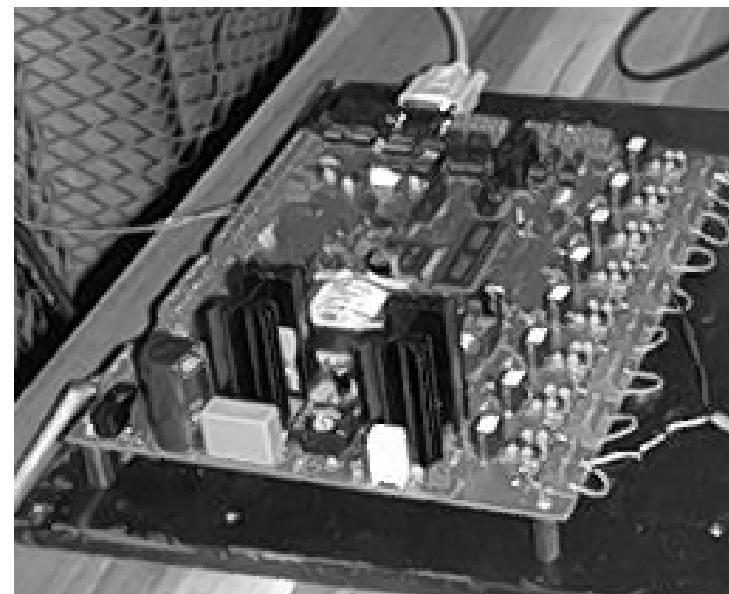
3. DSI



- Cable tray system for interconnections installed
- Physical plant wiring modifications completed
- Being extended to add additional loads
- Load center with measurement interface completed

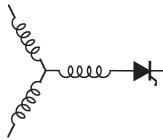
4. DGC

- CTs, PTs analog interface completed
- Software platform completed
- DSP control output interface being developed

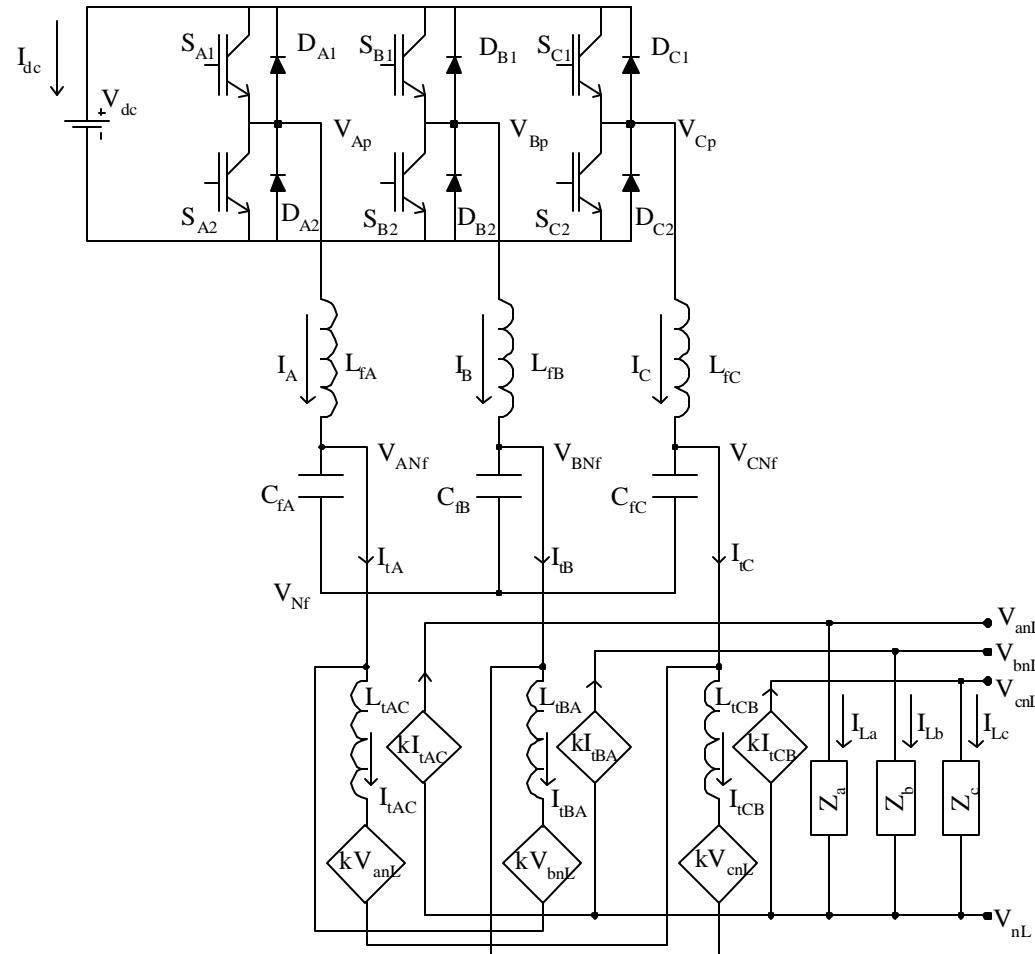


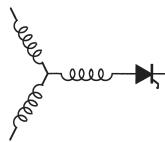
5. CSS

- Several computer simulation models in process
 - EMTP
 - Saber
 - Matlab-Simulink
 - Matlab
 - Mathcad



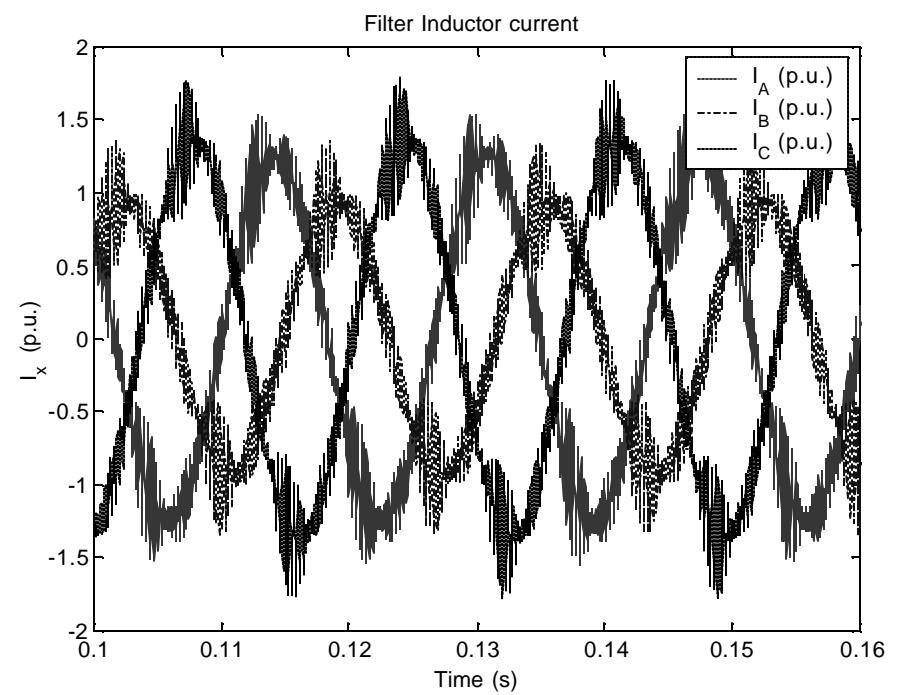
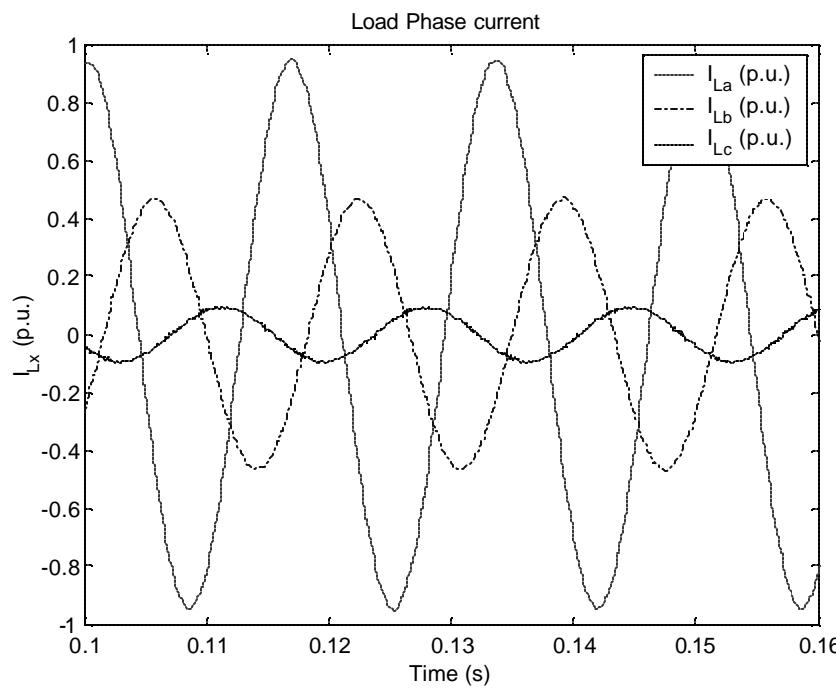
5. CSS



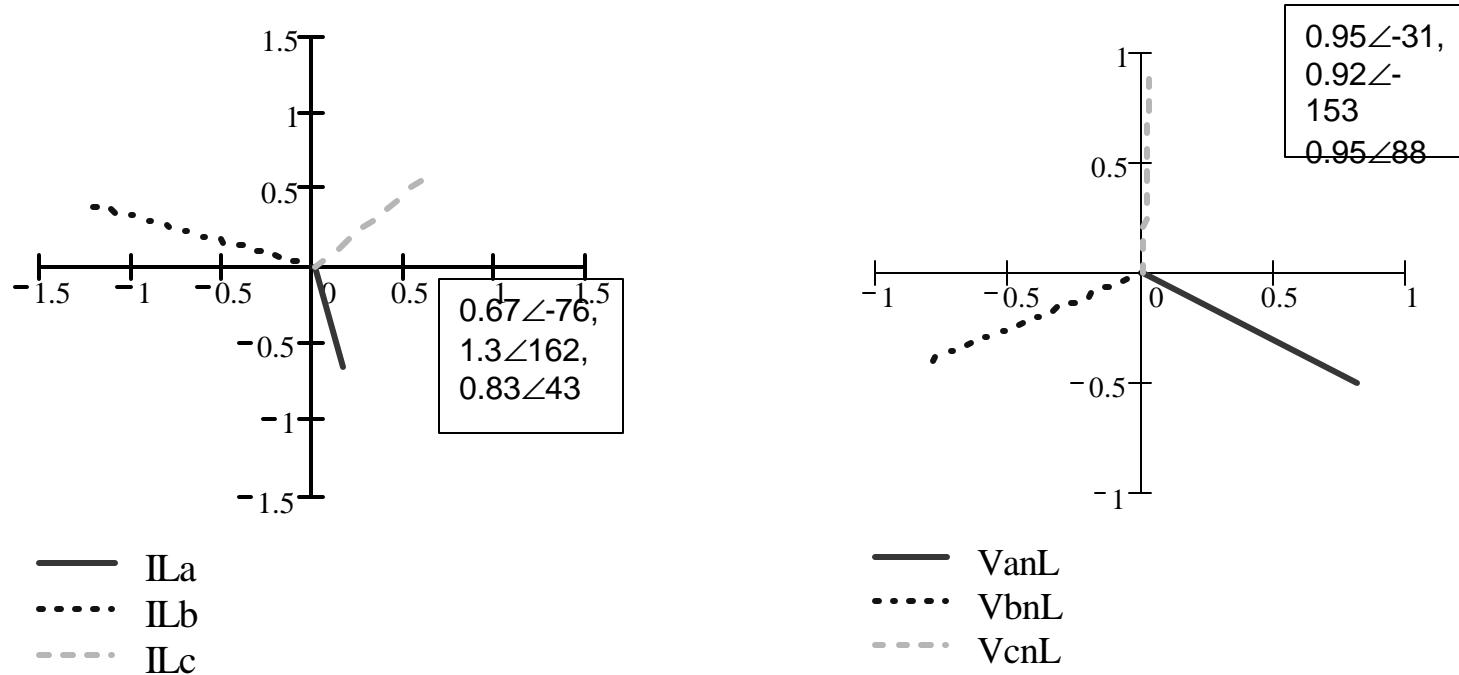


WEMPEC

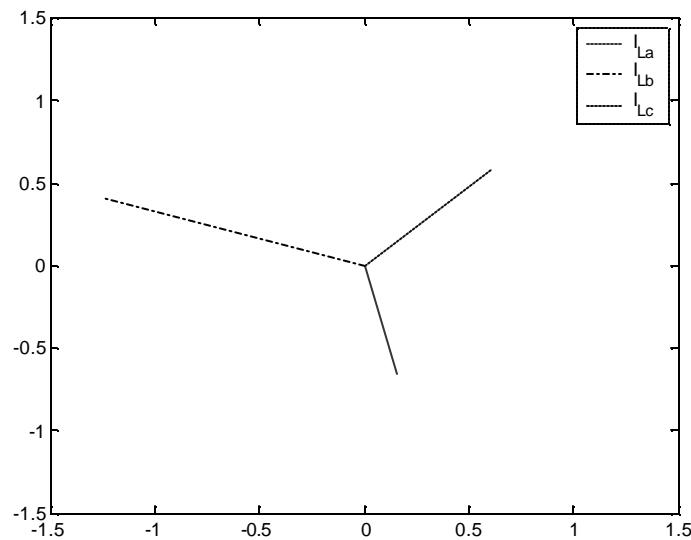
5. CSS



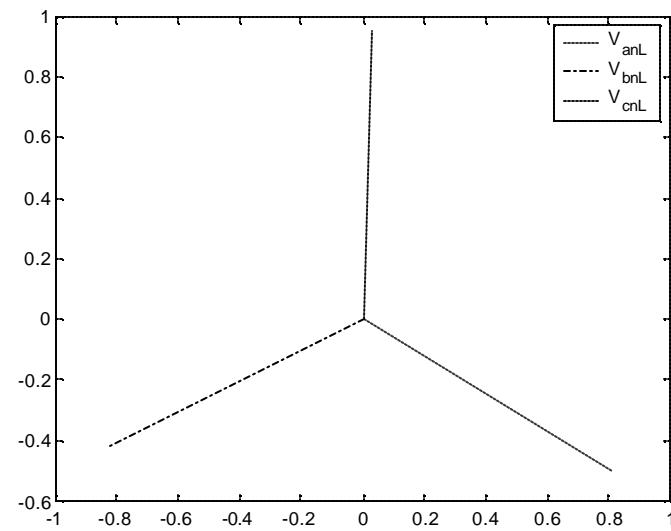
5. CSS - Analytical



5. CSS - Simulations

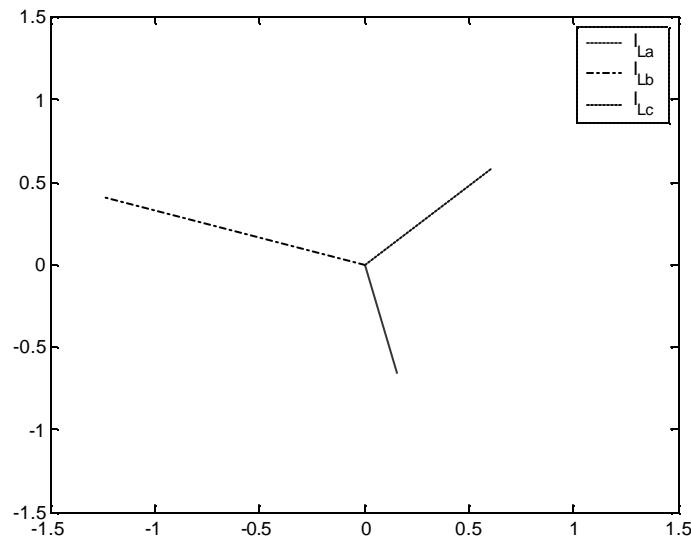


0.68∠-76,
1.3∠162,
0.83∠43

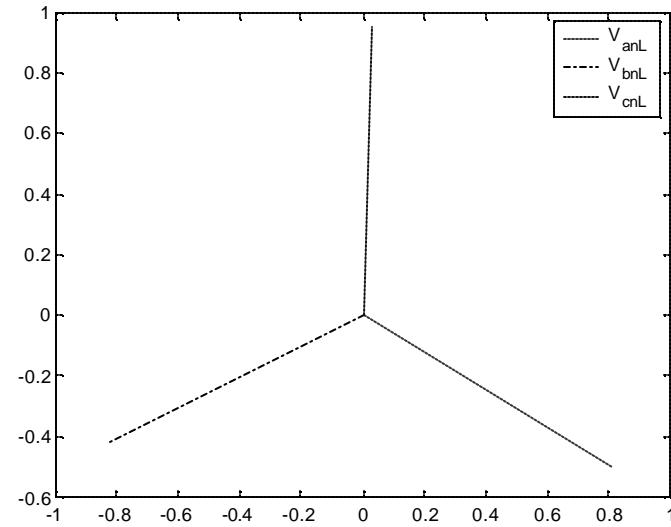


0.96∠-31,
0.92∠-
153
0.95∠88

5. CSS - Simulations

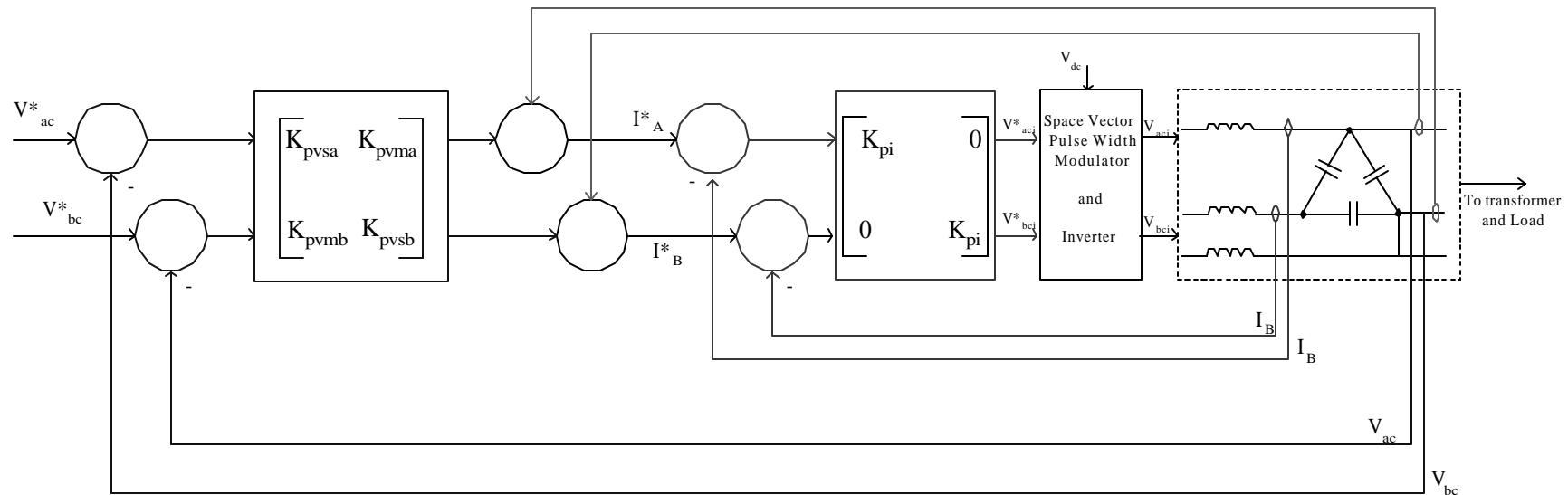


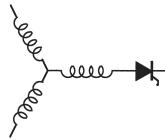
0.68∠-76,
1.3∠162,
0.83∠43



0.96∠-31,
0.92∠-
153
0.95∠88

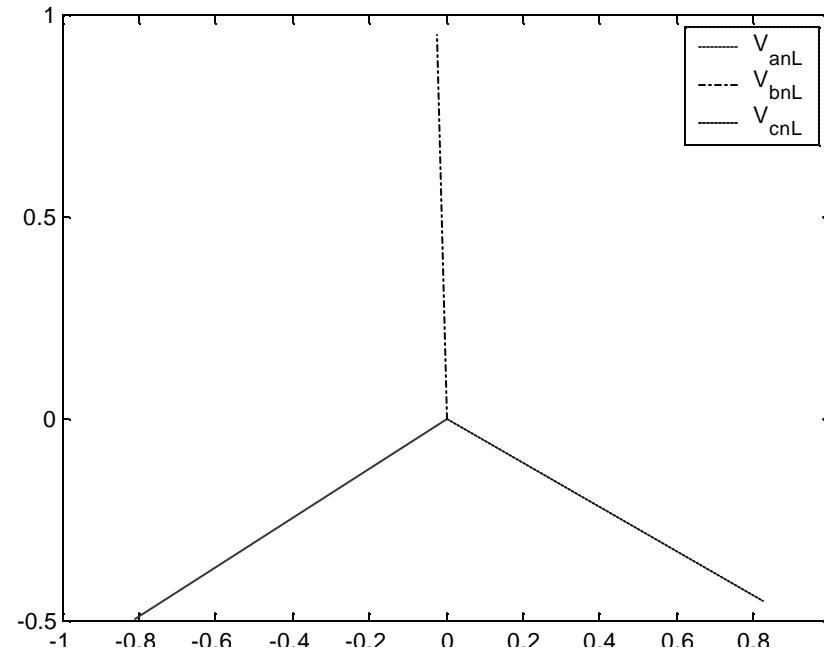
5. CSS – Simulations (Closed loop)



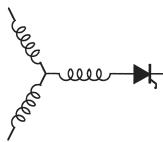


WEMPEC

5. CSS – Simulations (Closed loop)



$0.95\angle-29,$
 $0.95\angle91$
 $0.95\angle149$

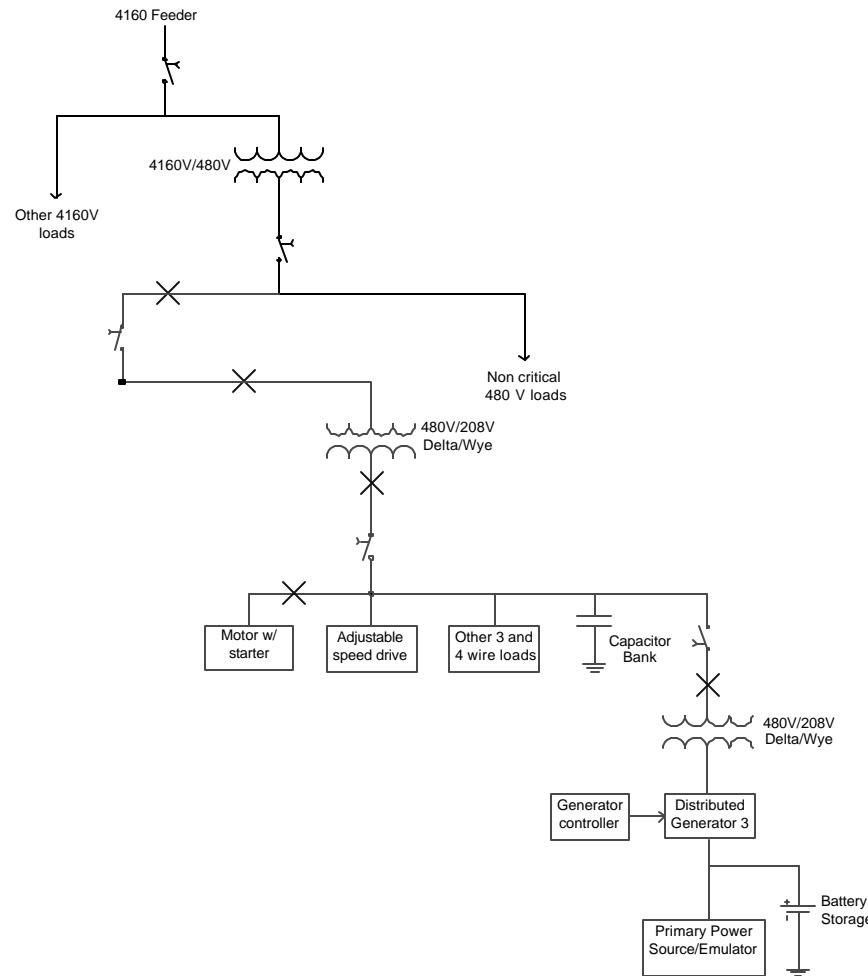


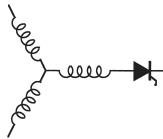
Year 1 Tasks

ID	Task Name	Start Date	End Date	Duration	2000			2001				2002	
					Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2
1	Development of power source emulator	12/15/00	12/3/01	252d									
2	Study of energy storage requirements	12/16/00	3/30/01	75d									
3	Demonstration of single inverter feeding complex loads	12/20/00	12/5/01	251d									
4	Development of DG inverter control	12/20/00	7/11/01	146d									
5	Computer simulation for Tasks 1-5	12/17/00	12/10/01	256d									
6	Expansion of lab scale microgrid												
7	Development of second PSE and Inverter												
8	Demonstration of two islanding and reconnection												
9	Demonstration of power quality solutions												
10	Computer simulation for Tasks 6-9												
11	Expansion fo lab scale microgrid												
12	Development of third PSE and Inverter												
13	Demonstration of decentralized control												
14	Demonstration of power quality solutions												
15	Demonstration of operation under faults												
16	Computer simulation for Tasks 11-15												

Evolution of Platform (Year 1)

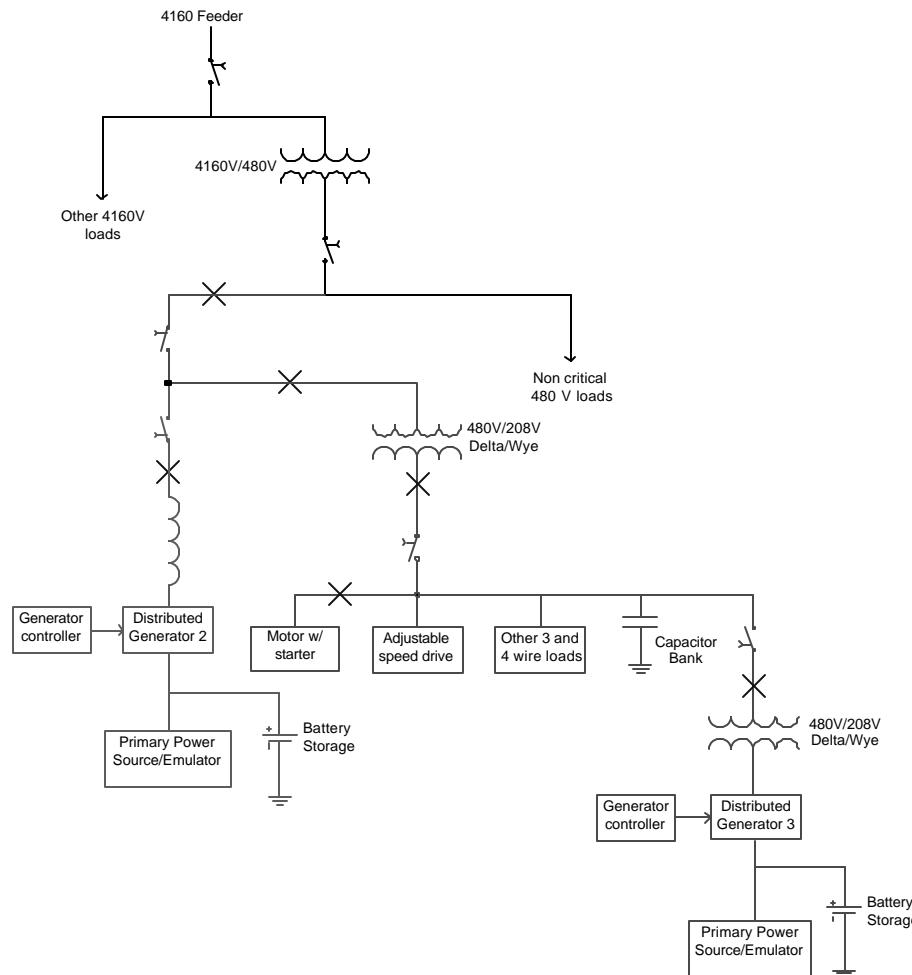
- Single inverter
- Complex set of loads

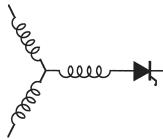




Evolution of Platform (Year 2)

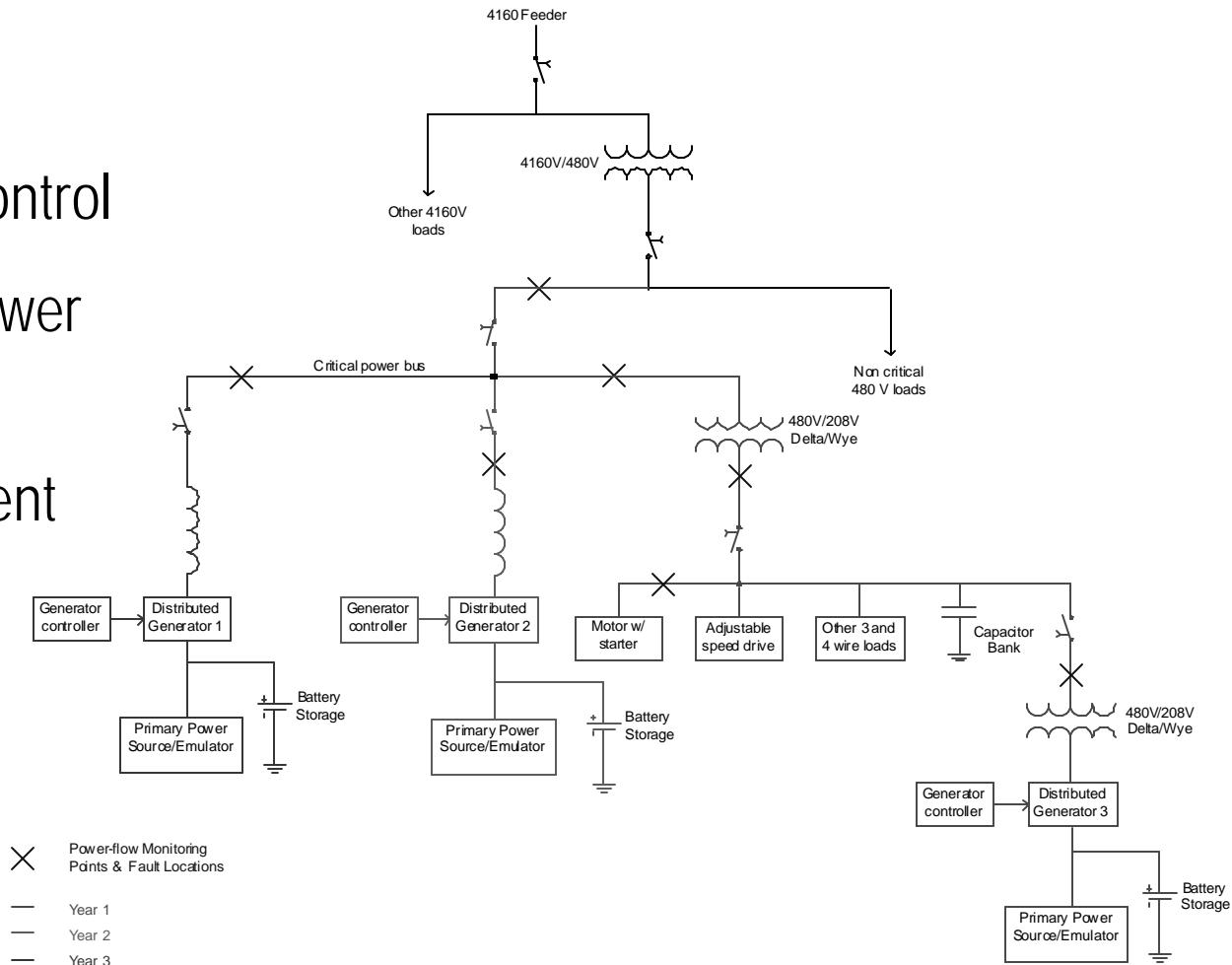
- Two inverters
- Islanding and reconnection
- Correcting power quality events (balanced)





Evolution of Platform (Year 3)

- Three inverters
- Decentralized control
- Single phase power quality events
- Fault management



Related Activities

- Completed project on control system development for an upcoming DG vendor
- One student summer internship completed at vendor facility
- 2 CEC projects on inverter cost reduction initiated
- Future Energy Challenge – DOE sponsored fuel cell inverter competition for students; Finalist
- Participation in DG protection short course
- Publications at professional and technical conferences
- Trying to procure Capstone turbine